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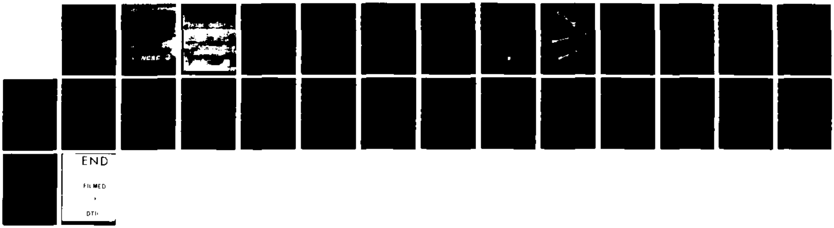

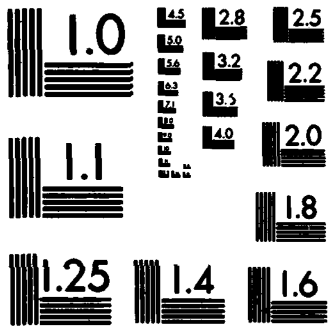
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TECHNICAL
MEMORANDUM
NCSC TM284-80

JUNE 1980

HYDRODYNAMIC STABILITY AND TOWING ANALYSIS OF THE MAGGIE II VEHICLE

J. W. CRANE

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NAVAL COASTAL SYSTEMS CENTER
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Underwater vehicles	Towing Analysis
Hydrodynamic coefficients	Tail sizing
Towing cables	Cable catenary

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An analysis of the hydrodynamic characteristics and stability of the MAGGIE II towed vehicle system has been performed. The vehicle's hydrodynamic coefficients and mass properties were determined from its geometry. The tail surfaces were sized to provide the required stability; the effects of tail size variations are presented as root locus plots. The vehicle's motions resulting from a heaving motion of the towing vessel have been predicted.

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INTRODUCTION

At the request of the Applied Physics Laboratory (APL) at Johns Hopkins University, NCSC investigated various aspects of the MAGGIE II vehicle, part of a second-generation prototype system of towed magnetometers. The following analyses were performed in the course of this study, the results of which are documented herein:

(1) Sizing of tail surfaces of a typical MAGGIE II vehicle configuration;

(2) Determination of vehicle stability, and specified cable catenaries, including scopes and tensions, for a given configuration;

(3) Estimation of vehicle response to input at the upper tow point; and

(4) Determination of the flow velocity over the afterbody.

VEHICLE CONFIGURATION

FIXED TAIL SURFACE SIZING

NCSC determined the sizing for the tail structure of the MAGGIE II vehicle; APL supplied the external configuration of the fuselage. The resulting vehicle is shown in Figures 1, 2, and 3. Mass characteristics calculated using a weight and balance program developed at NCSC[1] are given in Table 1, and hydrodynamic coefficients calculated by means of standard NCSC techniques[2,3] are presented in Table 2.

Three horizontal tail sizes, as detailed in Table 3, were considered. The tail configuration labeled Fin 4 is a modification of Fin 2, in which the leading edge has been swept 30 degrees. Fin 4 was selected for the vehicle.

The following characteristics of the tail configuration were considered in determining the relative effectiveness of the tail size alternatives.

---

[1]K.W. Watkinson, "The Midcohv Weight and Balance Computer Program (WTBAL)," Naval Coastal Systems Laboratory Informal Report 22074, September 1974.

[2]D.E. Humphreys and L.E. Bowen, "Prediction of Hydrodynamic Coefficients For Underwater Vehicles," paper presented at 1975 NAVSEA Hydromechanics Advisory Committee (SEAHAC) meeting, Monterey, CA., October 1975.

[3]D.E. Humphreys and K.W. Watkinson, "Prediction of Acceleration Hydrodynamic Coefficients For Underwater Vehicles From Geometric Parameters," Naval Coastal Systems Laboratory Technical Report 327-78, February 1978.

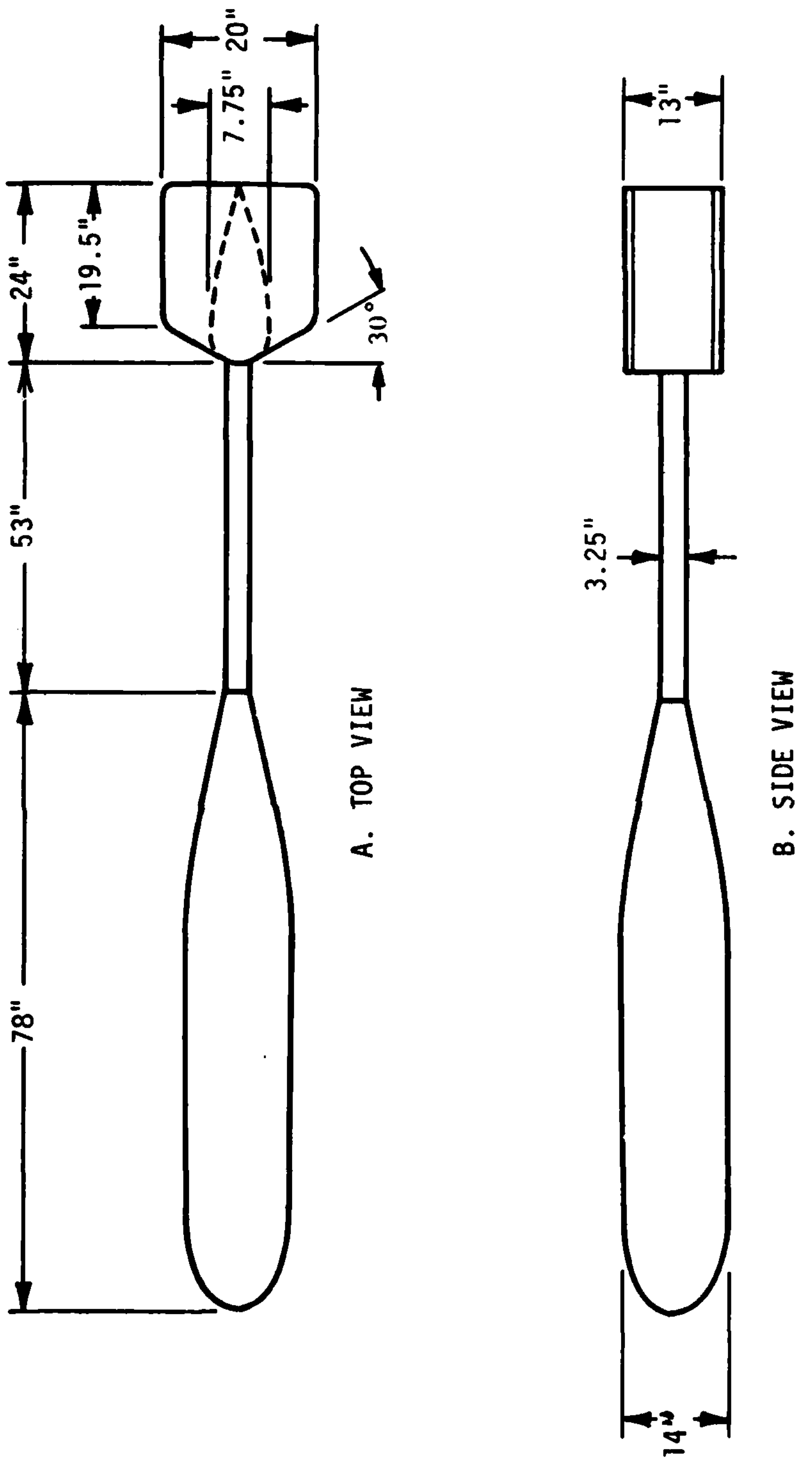
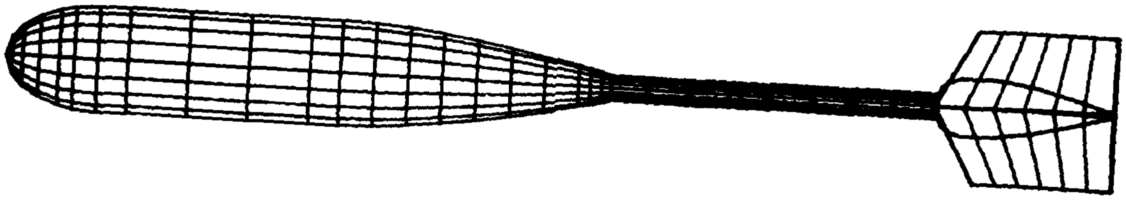
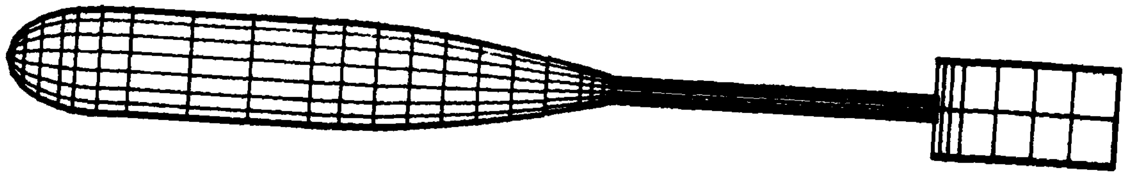


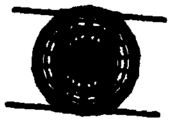
FIGURE 1. MAGGIE II VEHICLE DIMENSIONAL DRAWING



A. TOP VIEW



B. SIDE VIEW



C. FRONT VIEW

FIGURE 2. MAGGIE II VEHICLE (TOP, SIDE, AND FRONT VIEWS)

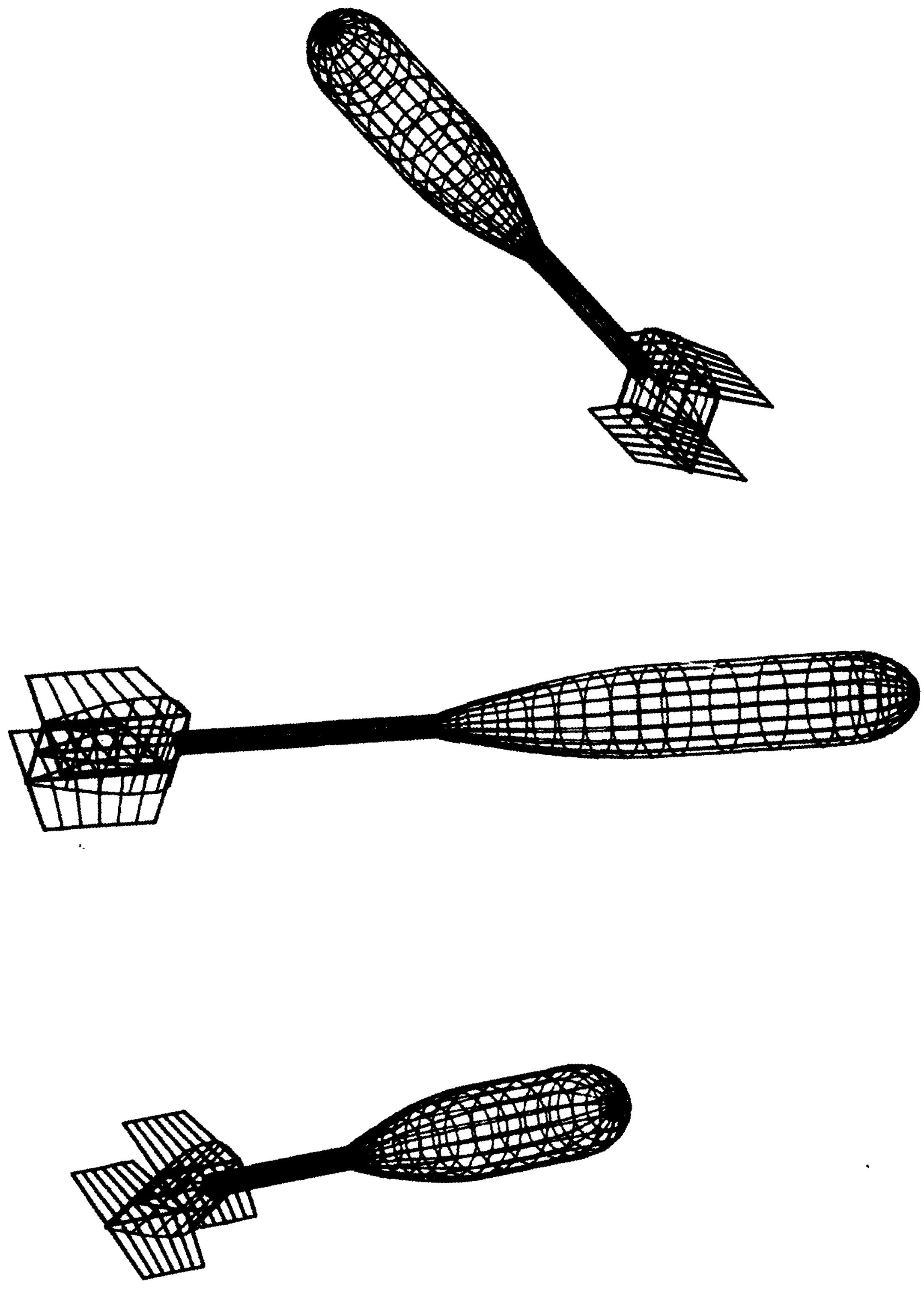


FIGURE 3. MAGGIE II VEHICLE (OBLIQUE VIEWS)

TABLE 1

MAGGIE II VEHICLE GEOMETRIC PROPERTIES

mass	= 11.09 slugs
I_x	= 1.61 slug/ft.^{2}
I_y	= 3.93 slug/ft.^{2}
I_z	= 3.93 slug/ft.^{2}
I_{xz}	= 0.00 slug/ft.^{2}
ℓ	= 12.93 ft.
$x_{nose/c.g.}$	= 3.11 ft.
$x_{nose/c.b.}$	= 3.11 ft.
$z_{c.b.}$	= -0.10 ft.
Cable length	= 50.00 ft.

The twin horizontal tails act as endplates on the vertical tail and increase its effective aspect ratio to range approximately from 2.5 to 3.0.[4] The horizontal tails also serve as bi-wings, thus effectively doubling their effective aspect ratio.[4] Interference effects at the junction of the vertical and horizontal tails were not considered.

CONTROL SURFACE SIZING

MAGGIE II control surfaces were sized to produce a displacement of 5 feet vertically and horizontally when fully deflected (±20 degrees). The nominal case examined was a speed of 8 knots and a cable length of 50 feet. The surfaces used were rectangular, with a chord of 1.33 inches and a semi-span of 4 inches. Planforms of the horizontal and vertical tails are shown in Figures 4 and 5, respectively.

---

[4] S.F. Hoerner and H.V. Borst, "Fluid-Dynamic Lift," (Published by the authors, 1975) pp. 3-9 to 3-10, pp 20-7 to 20-8.

TABLE 2 (Page 1 of 2)

MAGGIE II VEHICLE LONGITUDINAL HYDRODYNAMIC COEFFICIENTS, FIN 4

$X'_{uu} = -0.104 \times 10^{-2}$	$Z'_{w} = -0.520 \times 10^{-1}$	$M'_{w} = -0.276 \times 10^{-1}$
$X'_{\theta} = 0.206 \times 10^{-5}$	$Z'_{q} = -0.356 \times 10^{-1}$	$M'_{q} = -0.225 \times 10^{-1}$
$X'_{x} = -0.266 \times 10^{-3}$	$Z'_{\theta} = 0.109 \times 10^{-2}$	$M'_{\theta} = -0.347 \times 10^{-3}$
$X'_{z} = 0.$	$Z'_{x} = 0.$	$M'_{x} = 0.206 \times 10^{-5}$
$X'_{\dot{u}} = -0.120 \times 10^{-3}$	$Z'_{z} = -0.266 \times 10^{-3}$	$M'_{z} = 0.624 \times 10^{-4}$
$X'_{w} = 0.$	$Z'_{\dot{w}} = -0.992 \times 10^{-2}$	$M'_{\dot{w}} = -0.316 \times 10^{-2}$
$X'_{q} = -0.356 \times 10^{-3}$	$Z'_{\dot{q}} = -0.316 \times 10^{-2}$	$M'_{\dot{q}} = -0.210 \times 10^{-2}$

TABLE 2 (Page 2 of 2)

MAGGIE II VEHICLE LATERAL HYDRODYNAMIC COEFFICIENTS, FIN 4

$Y'_v = -0.580 \times 10^{-1}$	$K'_v = -0.545 \times 10^{-3}$	$N'_y = 0.300 \times 10^{-1}$
$Y'_p = -0.436 \times 10^{-3}$	$K'_p = -0.117 \times 10^{-3}$	$N'_p = 0.265 \times 10^{-3}$
$Y'_r = 0.368 \times 10^{-1}$	$K'_r = 0.265 \times 10^{-3}$	$N'_r = -0.224 \times 10^{-1}$
$Y'_\phi = -0.206 \times 10^{-5}$	$K'_\phi = -0.910 \times 10^{-4}$	$N'_\phi = -0.482 \times 10^{-6}$
$Y'_\psi = -0.109 \times 10^{-2}$	$K'_\psi = -0.845 \times 10^{-5}$	$N'_\psi = -0.256 \times 10^{-3}$
$Y'_y = -0.266 \times 10^{-3}$	$K'_y = -0.206 \times 10^{-5}$	$N'_y = -0.624 \times 10^{-4}$
$Y'_{\dot{v}} = -0.748 \times 10^{-2}$	$K'_{\dot{v}} = -0.578 \times 10^{-4}$	$N'_{\dot{v}} = 0.155 \times 10^{-2}$
$Y'_{\dot{p}} = 0.578 \times 10^{-4}$	$K'_{\dot{p}} = -0.155 \times 10^{-5}$	$N'_{\dot{p}} = 0.120 \times 10^{-4}$
$Y'_{\dot{r}} = 0.155 \times 10^{-2}$	$K'_{\dot{r}} = -0.120 \times 10^{-4}$	$N'_{\dot{r}} = -0.104 \times 10^{-2}$

TABLE 3

TAIL SIZE VARIATION

	FIN 1	FIN 2	FIN 3	FIN 4
Width (in.)	14.00	20.00	26.00	20.00
Length (in.)	24.00	24.00	24.00	24.00
Effective Span (in.)	6.50	12.50	19.50	12.50
Area (sq.in.)	156.00	300.00	444.00	248.00
Aspect Ratio	0.27	0.52	0.81	0.60
Effective Aspect Ratio Horizontal Tail	0.58	1.01	1.43	1.14
Taper Ratio	1.00	1.00	1.00	0.84
Leading Edge Sweep (deg.)	0.00	0.00	0.00	30.00
Aspect Ratio Vertical Tail	0.54	0.54	0.54	0.54
Effective Aspect Ratio Vertical Tail	1.85-2.5	2.5-3.0	3.00	2.5-3.0

To determine the magnitude of the displacement when the control surface is deflected, the depth (Z) transfer function is examined. The Z transfer function is formed from the w and θ transfer functions and is given by

$$\frac{Z(s)}{\delta_e(s)} = \frac{1}{s} \left(\frac{w(s)}{\delta_e(s)} - u_o \frac{\theta(s)}{\delta_e(s)} \right)$$

$$= \frac{.0041\ (s + 49.45)}{(s + 10.66)(s^2 + 0.170\ s + 0.039)}.$$

Application of the Final Value Theorem of Laplace Transforms for a step input in elevator results in steady state depth change of

$$z_{\text{steady state}} = \lim_{s \to o} s \frac{Z(s)}{\delta_e(s)} \frac{1}{s} \delta_e$$

$$= 0.49 \text{ ft./deg.}$$

since the maximum elevator is ±20 degrees, final steady state depth change will be 10 feet. Also, because pigtail restoring forces vary inversely with pigtail length, doubling or halving this length will double or half the depth change. Doubling the elevator area will also double the depth change.

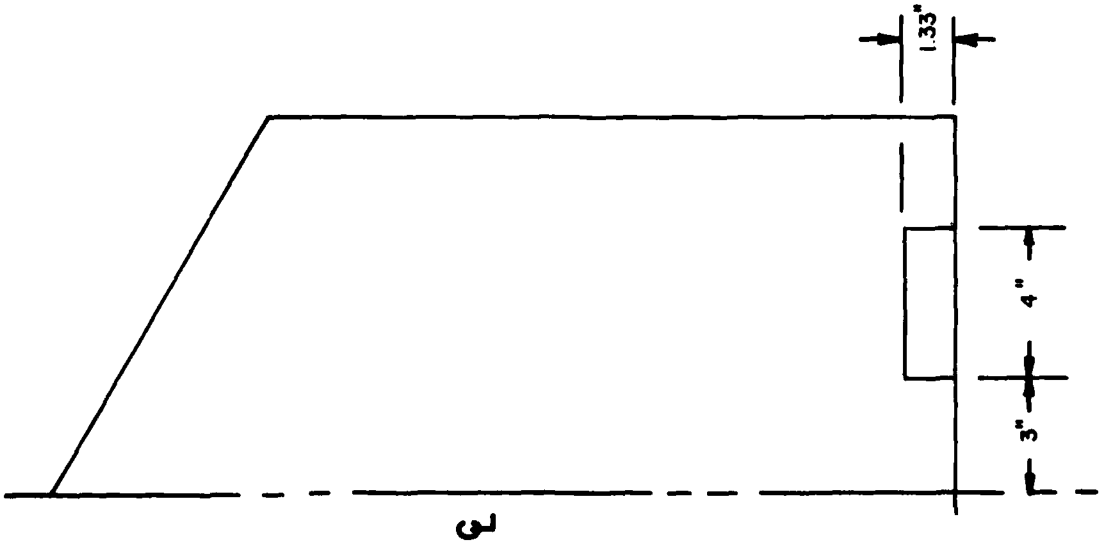


FIGURE 4. HORIZONTAL TAIL WITH ELEVATOR

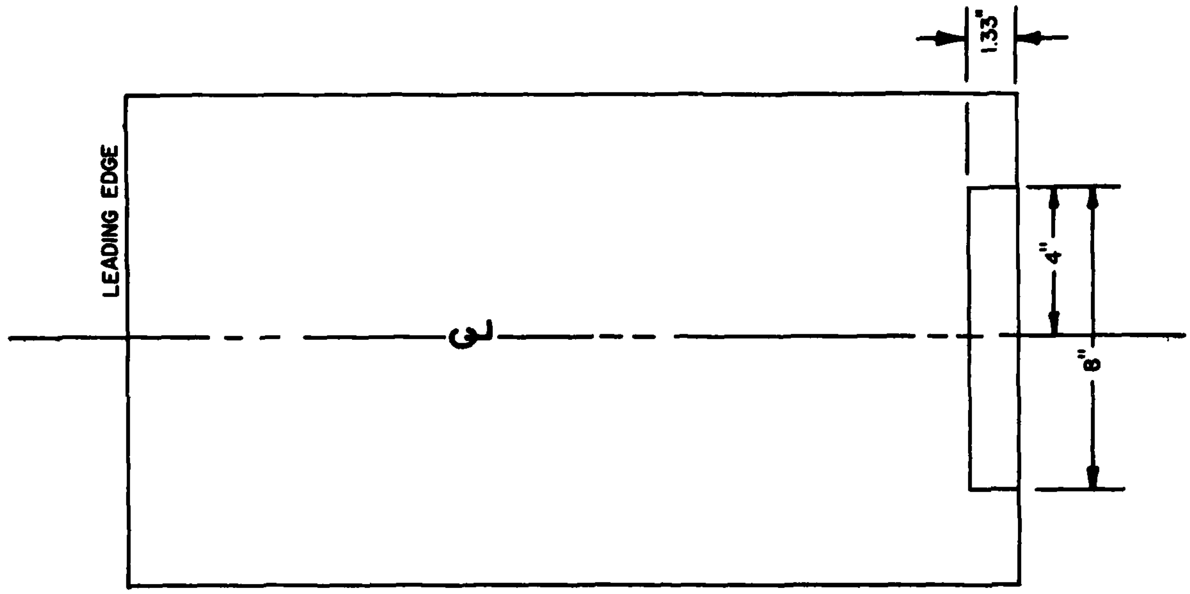


FIGURE 5. VERTICLE TAIL WITH RUDDER

The Y transfer function is formed from the v and ψ transfer functions and is given by

$$\frac{Y(s)}{\delta_r(s)} = \frac{0.00128\ (s + 675.1)}{(s + 20.35)(s^2 + 0.157\ s + 0.040).}$$

The steady state gain for a step rudder input is

$$y_{\text{steady state}} = 1.06 \text{ ft./deg.}$$

Changing the cable length and the control surface area will have similar effects on the y response.

VEHICLE STABILITY

BASE CASE

The stability of the MAGGIE II towed body and pigtail was examined for various speeds and pigtail lengths. The base case used in this analysis was a speed of 8 knots and a pigtail length of 50 feet. The corresponding longitudinal and lateral roots for the base case are given in Table 4. Except for the roots marked roll and surge, longitudinal and lateral roots are similar because the vehicle has two almost identical planes of symmetry. Roll roots are moderately damped, with a maximum time to half amplitude of 1.9 seconds and a period of 9.1 seconds. This can be improved by increasing the c.b./c.g. separation.

TABLE 4

BASE CASE ROOTS

	Longitudinal	ζ	ω_n (rad./sec.)
	-1.30, -10.66	1.61	3.71
	-0.09 ± 0.18	0.45	0.20
*	-0.20 ± 0.11	0.87	0.24
	Lateral Roots	ζ	ω_n (rad./sec.)
	-1.41, -20.3	2.03	5.35
	-0.08 ± 0.18	0.39	0.20
**	-0.37 ± 0.69	0.47	0.78

* Surge
** Roll

TOWING SPEED

Towing speed was varied from 2 knots to 14 knots with a constant pigtail length of 50 feet. Results of this analysis are presented in root locus form in Figure 6. Examination of the roll roots reveals that natural frequency does not vary with speed, due to the fact that ω_n is a function of only the c.b./c.g. separation. Damping ratio does, however, increase with an increase in speed because of the presence of the tail.

Surge roots are dependent upon the X'_x cable derivative and the vehicle drag coefficient; natural frequency varies proportionally with towing speed while damping ratio remains constant. Both roll and surge motions are decoupled from the other motions of the vehicle.

Examination of the remaining roots reveals that the damping ratio of the oscillatory pairs continues to be constant while speed increases. Damping ratio of the real roots decreases but remains greater than unity. Natural frequency, varying linearly with speed, increases in conjunction with speed for the remaining real roots. Motion associated with these roots consists of w,q,z,θ longitudinal motion and v,r,y,ψ lateral motion.

PIGTAIL LENGTH

Pigtail length was varied from 25 to 300 feet while a constant speed of 8 knots was maintained. Figure 7 presents the results of this analysis in root locus form. Examination of the roll and surge roots reveals that only the surge roots are affected by cable length variation. Increasing pigtail length drives the surge roots toward their untethered values, 0.0 and 0.42, because cable length appears inversely in the X'_x derivative in the surge mode.

Base case real roots are only slightly affected by changes in pigtail length. Increasing the length results in a decrease in frequency of oscillation while time to half amplitude remains constant. Frequency of oscillation is dependent upon the cable derivatives which vary inversely with pigtail length, while damping ratio is predominantly speed dependent.

STATIC CATENARY

The static catenaries originally proposed by APL were analyzed using the three-dimensional cable program developed by Wang.[5] Results of this

[5]H.T. Wang, "A Fortran IV Program for the Three-Dimensional Steady State Configuration of Extensive Flexible Cable Systems," Naval Ship Research and Development Center Report No. 4384, September, 1974.

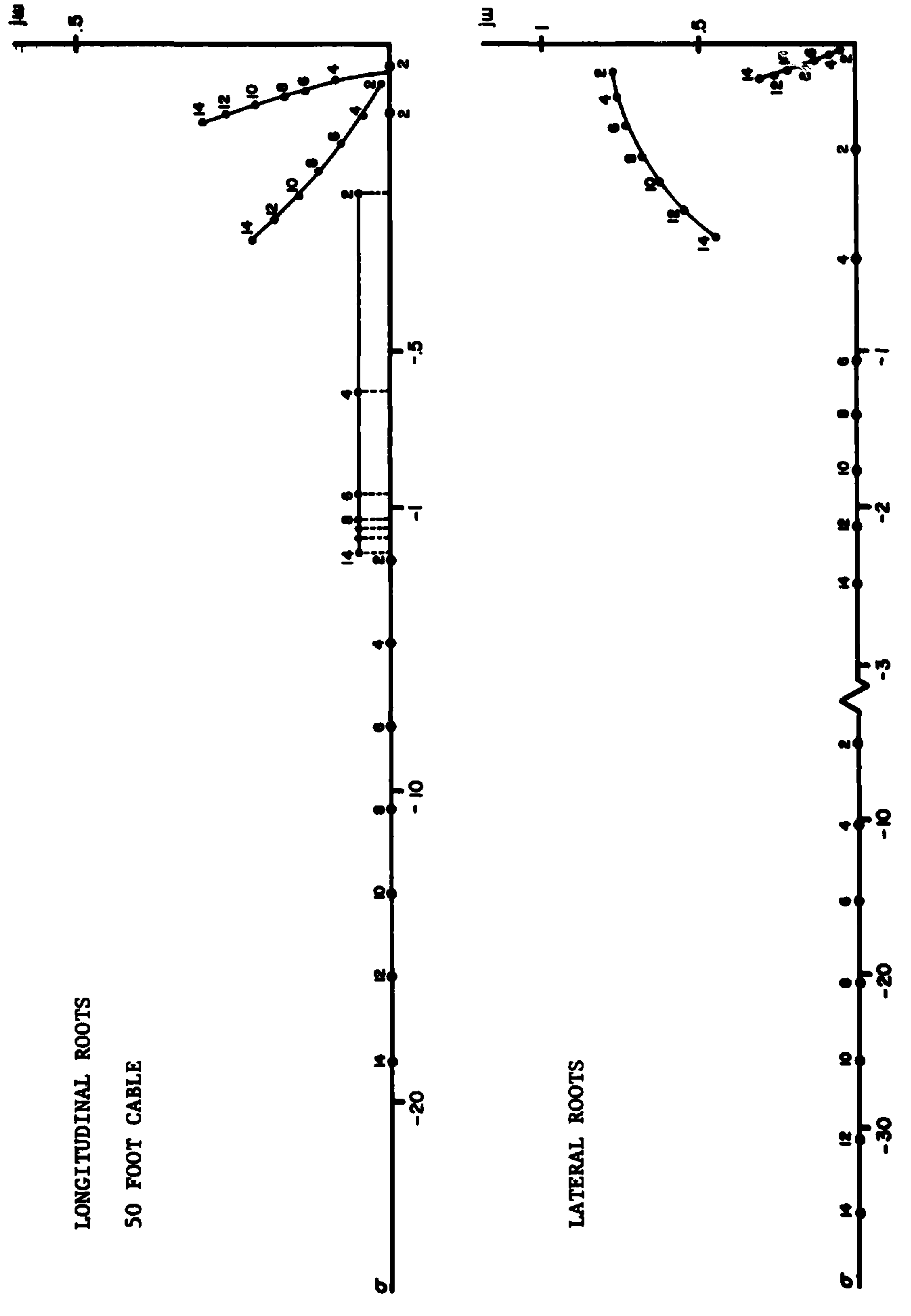


FIGURE 6. EFFECT OF VARYING TOW SPEED ON VEHICLE STABILITY

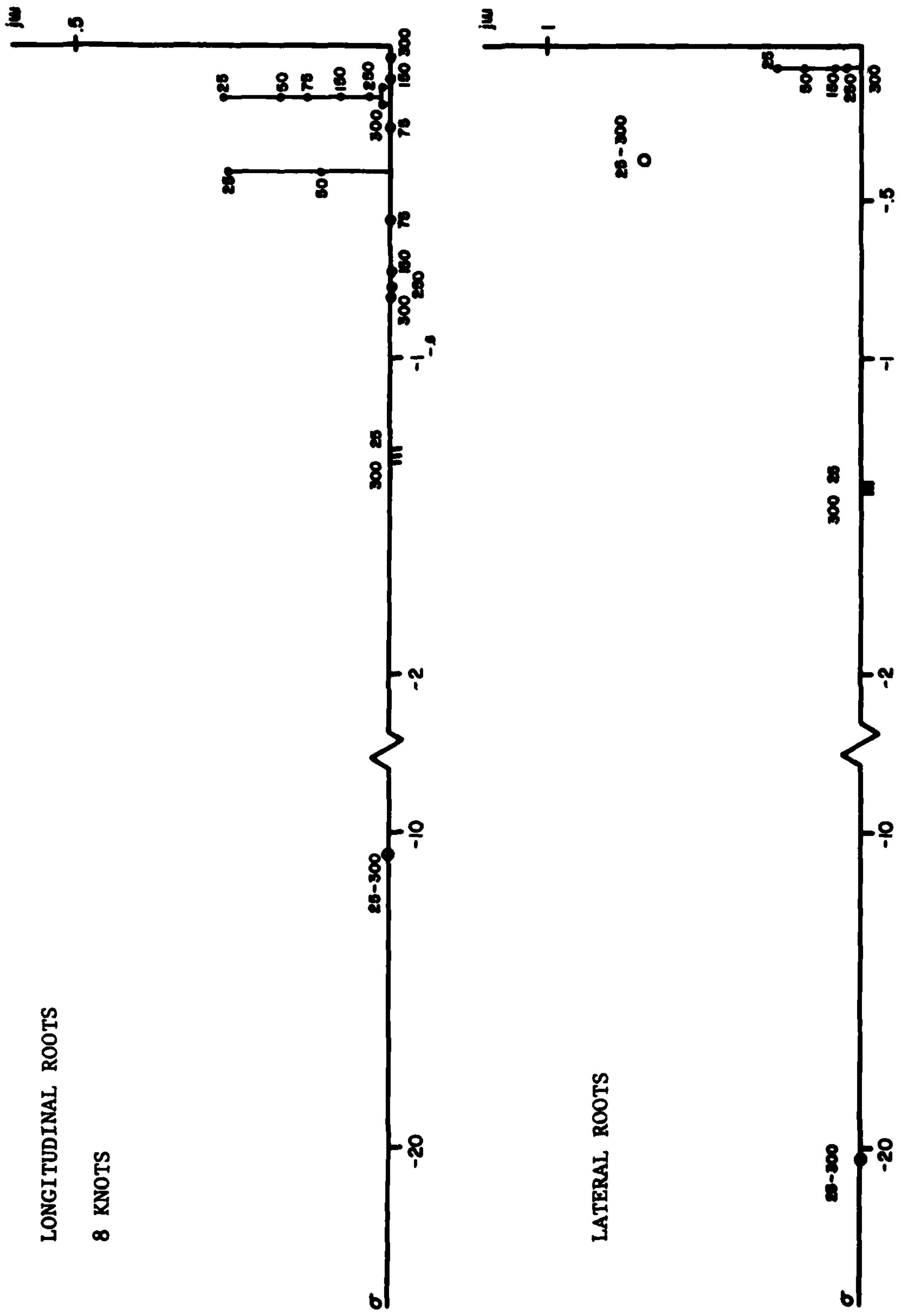


FIGURE 7. EFFECT OF VARYING PIGTAIL LENGTH ON VEHICLE STABILITY

analysis are presented in Table 5. A typical MAGGIE II cable system is shown in Figure 8.

The depressor used for the purposes of this study was the Classic Thicket,[6] with a tail incidence angle of -2½ degrees. Lengths of the pigtails were such that the two MAGGIE towed bodies trailed at equal distances from the tow point at a speed of 8 knots. Lengths of the cable segments were determined such that the first towed body was at a depth of 100 feet, the second body was at 500 feet, and the depressor was at 600 feet. Indicated cable sections were faired with Fathom Flexnose Fairing; otherwise, ribbon or hair fairing was used.

The cable configurations adopted by APL[7] are constructed such that 100 foot lengths may be added or removed, as is illustrated in Figures 8 and 9.

VEHICLE RESPONSE TO UPPER TOW POINT INPUT

To determine the response of the MAGGIE system to a heaving motion at the upper tow point, it was necessary to create a model of the entire system of MAGGIE bodies, cable, and depressor. The cables were modeled as five groups of springs and dampers, one group for each cable segment as was shown in Figure 8.

Input at the tow point was to have a 5-foot amplitude, corresponding to Upper Sea State 3 as indicated in Figure 10, the Pierson-Moskowitz Sea Spectra.[8] This also corresponded to a frequency of approximately 1 radian per second. Response of the system was determined over the range of frequencies from 0.01 to 10 radians per second. The output amplitude was normalized with respect to the input amplitude as is illustrated in Figures 11 and 12 for Bodies 1 and 2, respectively. Response data for frequencies greater than 1.2 radians per second corresponds to Sea States 1 and 2.

Body 1 response peak occurs at approximately 0.08 radians per second (Sea State 4). The amplitude of the z response at peak is 1.12 percent of the input, while the θ or pitch response is 0.4 degree per foot.

---

[6]Charles W. Sieber, "Design and Evaluation of a Large Towed Winged Depressor for Project Classic Thicket," Naval Ship Research and Development Center Report No. SPD-487-04, October, 1974.

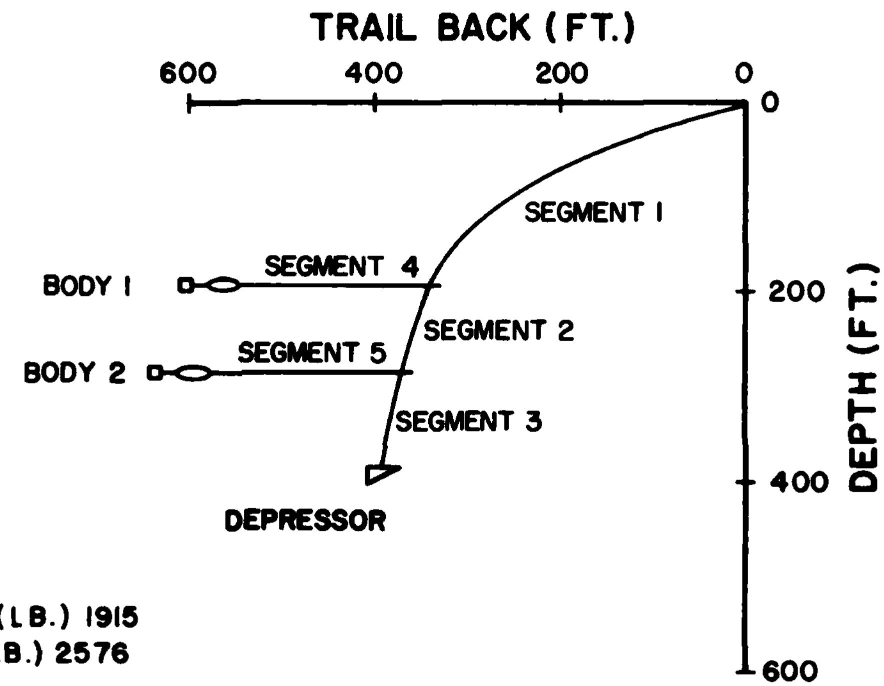
[7]B.F. Fuess, "Cable Catenary for MAGGIE II Sensor System," Johns Hopkins University Applied Physics Laboratory Memorandum No. BFD-3-78-002, 30 March 1978

[8]W.J. Pierson and L. Moskowitz, "A Proposed Spectral Form Based on the Similarity Theory of S.A. Kitaigorodski," Report No. 63-12, Geophysical Sciences Laboratory, N.Y. University, 1963.

TABLE 5
CABLE CATENARY DATA

Cable Config.	Total Scope(ft)	Tension Winch(lb)	ϕ (°)	Depth (ft)	Trail Back (ft)	T Initial (lb)	ϕ Initial (deg)	T Final (lb)	ϕ Final (deg)	Δs (ft)	Δd (ft)	Δx (ft)	Dia. (inch)	Faired (y or n)
1	858	2853	57.0	600	593	1915	9.8	1981	33.9	109	100	41.7	.55	N
						2003	34.8	2622	53.3	572	400	406.1	1.20	Y
						2654	53.82	2853	57.0	177	100	145.2	1.20	Y
2*	3611	3440	83.4	600	3484	1731	1.0	1763	38.7	110	100	39.6	.55	N
						1782	39.4	2829	84.8	2560	400	2508.7	.85	N
						2888	84.9	3440	83.4	941	100	935.3	1.20	N
3	657	2146	34.4	600	255	1915	9.8	1936	14.0	102	100	21.0	.625	Y
						1946	15.1	2080	30.2	436	400	169.6	.625	Y
						2100	31.1	2146	34.4	119	100	64.4	.625	Y
4	716	2623	46.5	600	368	1915	9.8	1985	17.4	103	100	24.4	1.20	Y
						1997	18.5	2444	41.7	475	400	245.2	1.20	Y
						2471	42.2	2623	46.5	141	100	98.4	1.20	Y
5*	707	2056	71.2	600	276	1731	1.0	1738	4.6	100	100	4.8	.55	N
						1741	5.6	1888	25.9	420	400	116.7	.85	Y
						1914	27.5	2056	71.2	187	100	154.1	1.20	N
6	730	2298	70.6	600	350	1915	9.8	1930	13.0	102	100	20.1	.55	Y
						1937	13.8	2122	31.1	436	400	169.8	.85	Y
						2153	32.5	2298	70.6	192	100	159.9	1.20	N
7	696	2853	43.4	600	333	1915	9.8	1963	16.3	103	100	23.2	1.0	Y
						1975	17.4	2288	38.6	459	400	217.4	1.0	Y
						2313	39.3	2421	43.4	134	100	88.2	1.0	Y

* Data is questionable under estimate's actual catenary



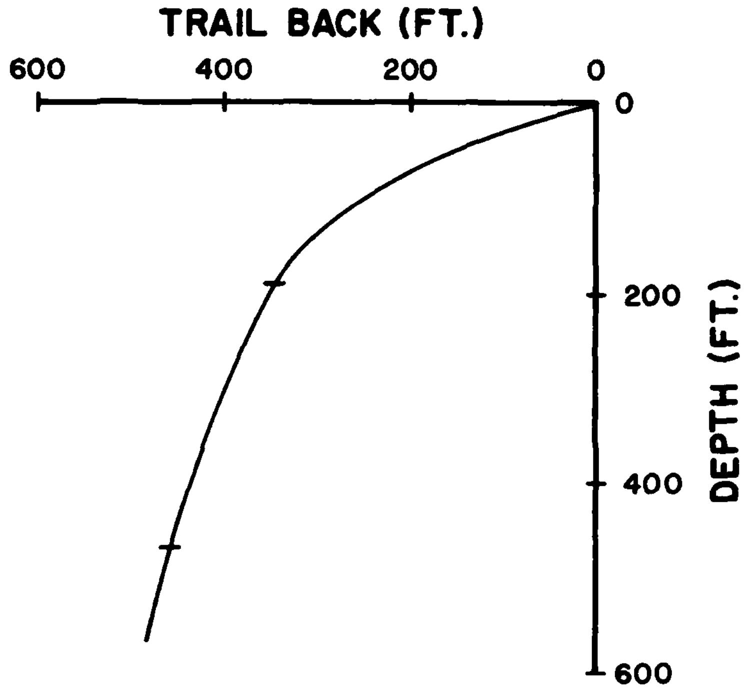
INITIAL TENSION (LB.) 1915
FINAL TENSION (LB.) 2576

CABLE

SECT.	LENGTH	DIA.	TYPE
1	100'	1.0"	FLEX
2	100'	1.0"	FLEX
3	400'	1.0"	BARE

TOTAL SCOPE (FT.) 600

FIGURE 8. PROPOSED CABLE CATENARY WITH 600 FOOT SCOPE



INITIAL TENSION (LB.) 1915
FINAL TENSION (LB.) 2864

CABLE SECT.	LENGTH	DIA.	TYPE
1	100'	1.0"	FLEX
2	300'	1.0"	FLEX
3	400'	1.0"	BARE

TOTAL SCOPE (FT.) 800

FIGURE 9. PROPOSED CABLE CATENARY WITH 800 FOOT SCOPE

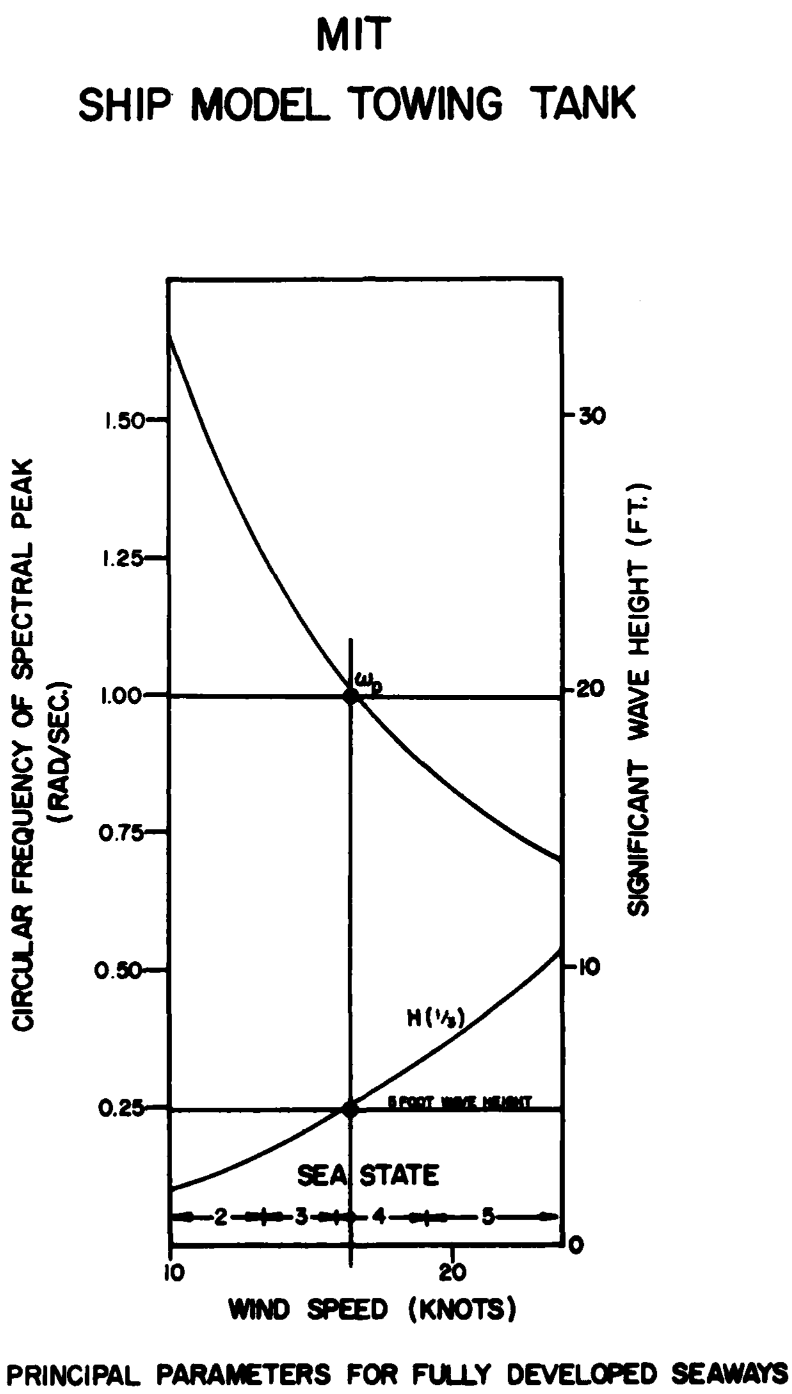


FIGURE 10. PIERSON-MOSKOWITZ SEA SPECTRA

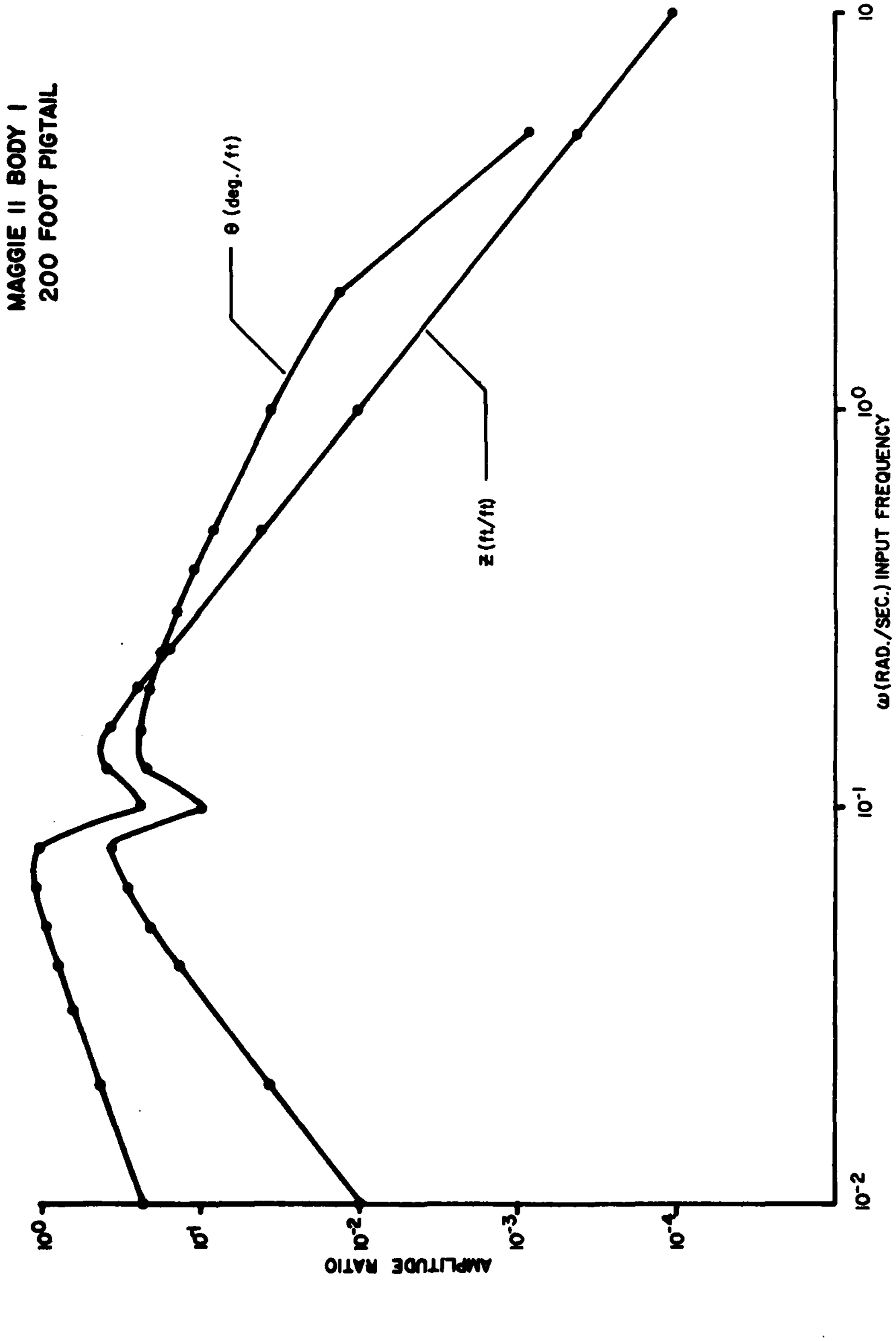


Figure 11. RESPONSE OF BODY 1 TO HEAVING TOW POINT

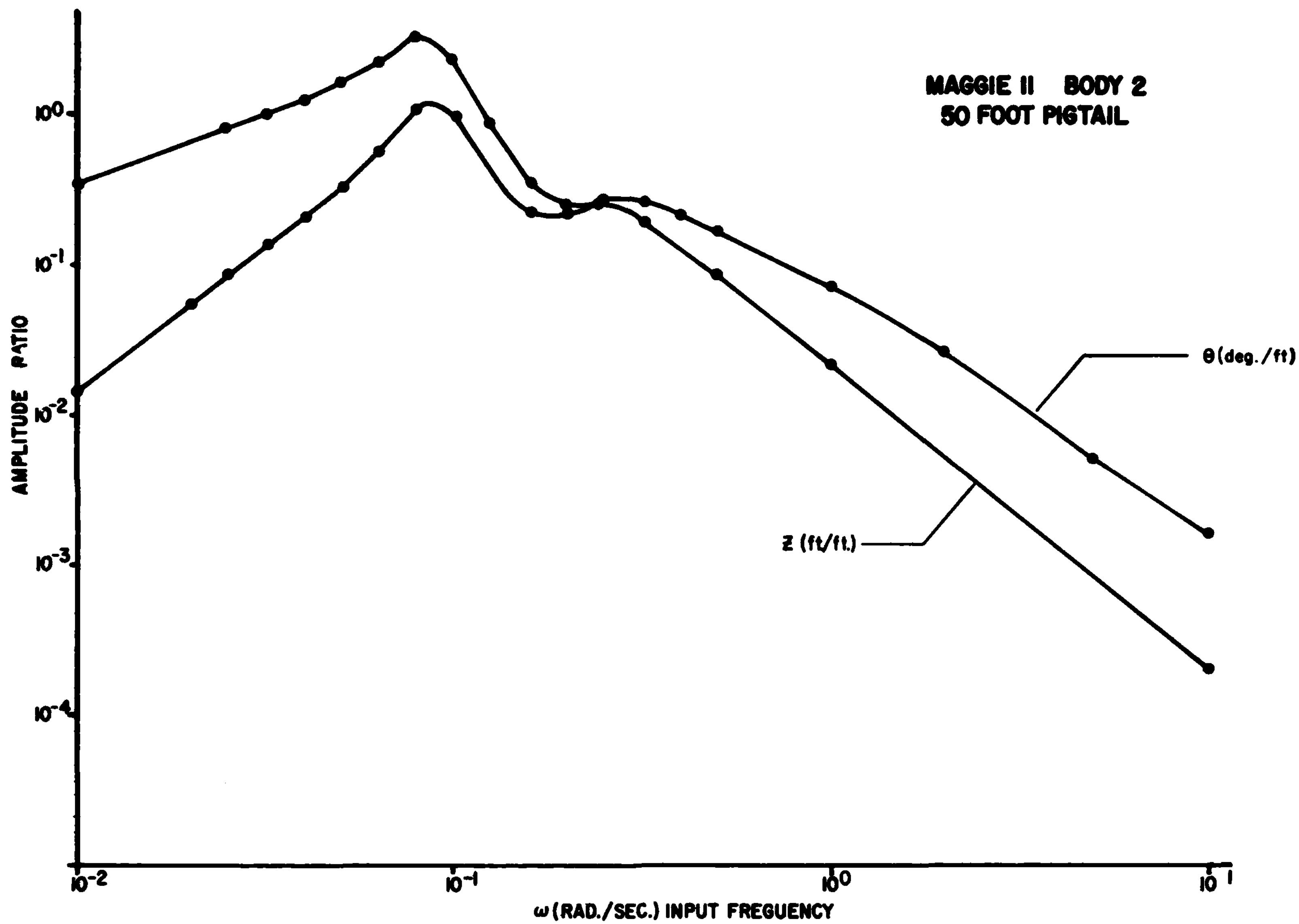


Figure 12. RESPONSE OF BODY 2 TO HEAVING TOW POINT

In the range of frequencies from 0.1 to 0.2 radian per second, however, the z response is only 32 percent of the input and the θ response is 0.25 degree per foot.

The peak responses of Body 2 are not as sharply defined as those of Body 1. They occur in the range of frequencies from 0.07 to 0.3 radian per second, with a maximum z amplitude of 32 percent of the input, and θ amplitude of 1.20 degrees per foot at 0.08 radian per second. The maximum z amplitude near 0.25 radian per second is 25 percent of the input. The maximum θ amplitude of 0.25 degree per foot is only slightly less than the peak θ amplitude.

Frequencies less than 1 radian per second are outside the operating envelope of the vehicle. Motion expected in Sea State 3 for Body 1 is a one percent z response and 0.04 degree per foot θ response. Motion expected for Sea States less than 3 will be approximately the same as those predicted for Sea State 3.

FLOW VELOCITY OVER AFTERBODY

Figure 13 presents the two-dimensional potential flow solution for pressure distribution over the afterbody of the MAGGIE vehicle. Pressure distribution data was obtained by representing the body as a series of source panels, and then solving for source strengths which satisfy the local boundary condition of each panel such that the velocity normal to each panel equals zero.

The local velocity over the afterbody is found from the pressure distribution data by

$$V^2 = V_\infty^2 \ (1 - C_p).$$

CONCLUSIONS

Analysis of the MAGGIE II vehicle has shown in to be stable and its fixed tail size to be adequate. Determination of sizing for tail control surfaces should be based upon the amount of cable to be used in the tow tank tests. The proposed cable catenaries have been analyzed and the tensions at the winch determined acceptable. Motion of the bodies induced by the upper tow point was found to be acceptable through Sea State 3.

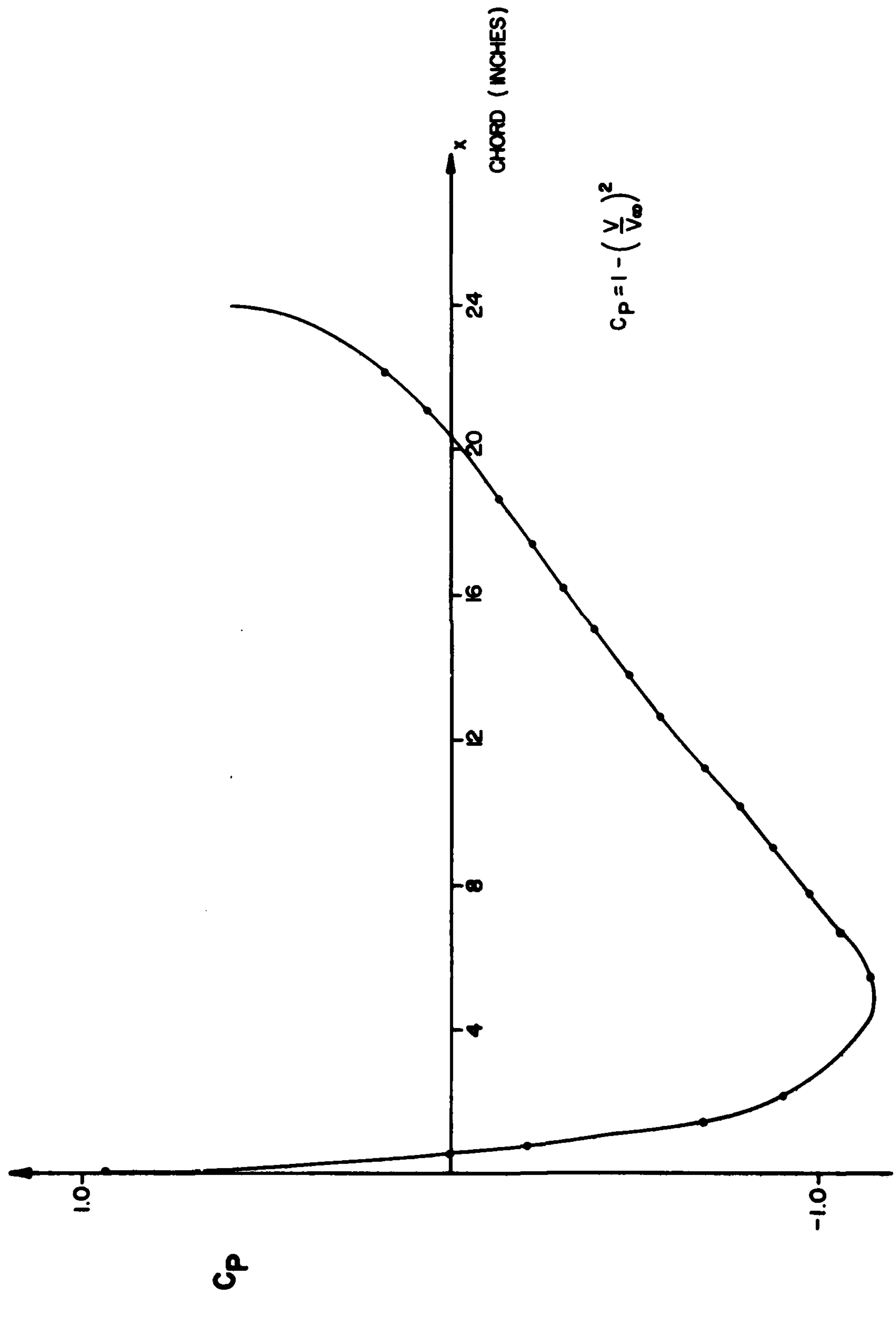


FIGURE 13. PRESSURE DISTRIBUTION OVER MAGGIE 11 AFTERBODY

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